National Exams May 2013

04-Chem-A6, Process Dynamics & Control

3 hours duration

**NOTES:**

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
   Any non-communicating calculator is permitted.

3. FIVE (5) questions constitute a complete exam paper.
   The first five questions as they appear in the answer book will be marked.

4. Each question is of equal value.

5. Most questions require an answer in essay format. Clarity and organization of the answer are important.

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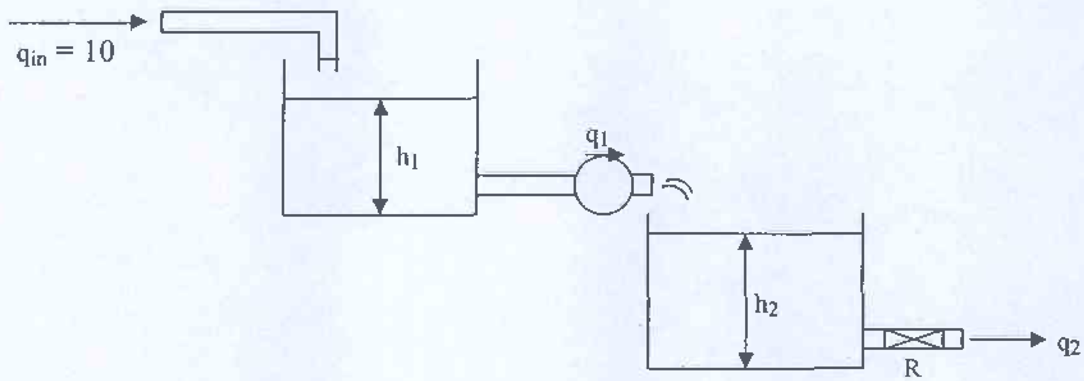
**Problem #1** (20% total)

Two tanks are connected in series in a non-interacting fashion as shown in the figure.




Assume: $\rho = 1$ Kg/m$^3$ A = 1 m$^2$(A-cross-section of each tank)

$$q_2 = \frac{1}{2}\sqrt{\frac{\Delta P}{\rho g}}$$ (m$^3$/sec) and $q_1$ is determined by a pump.

$q_{in}$ = 10 m$^3$/sec and remains constant. The initial level in tank 1 is $h_1(t=0) = 10$ m. $q_1$ is the manipulated variable. All q's are volumetric flow rates.

(10%) (a) Show the differential equations that describe the behaviour of $h_1(t)$ and $h_2(t)$.

(10%) (b) Compute transfer functions between $h_1$ to $q_{in}$ and $h_2$ to $q_{in}$.

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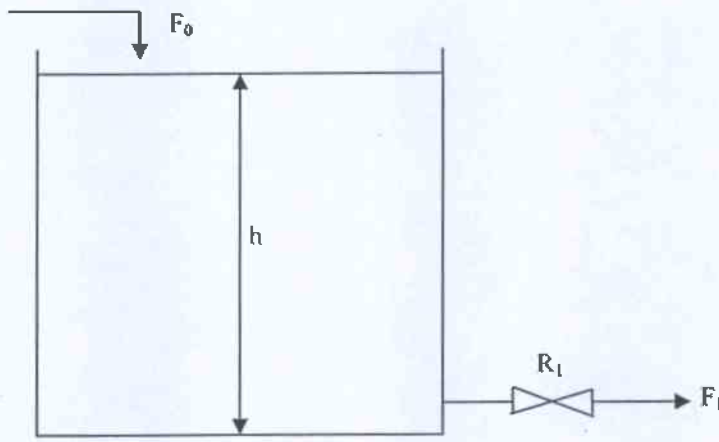
**Problem #2** (20% total)

For the draining tank shown in the figure




Compute the level h(t) with respect to an initial steady state for the following two cases:

(10%) (a) a unit step in inlet flow $F_0$

(10%) (b) a square unit pulse in inlet flow $F_0$ of duration $t_p$ starting from t=0.

The cross section area is $1m^2$. The initial level is 7m.

The flow out is given by $F_1 = R_1 \bullet h$, where the coefficient $R_1 = 4\frac{m^2}{min}$, $\tau_p$=5 min.

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**Problem #3** (20% total)

A process is described by the following transfer function:

$$G_p = \frac{5(s-1)e^{-5s}}{100s+1}$$

(10%) (a) Design an IMC controller for this process. Show your design using a block diagram. Select the IMC filter to be of 1$^{st}$ order with a time constant $\tau = 10$. Do not use Pade approximation.

(10%) (b) Compute and plot qualitatively the closed loop response of the system to a unit step in set point. Assume a perfect model (i.e. no model error).

**Problem #4** (20% total)

A process given by:

$$G_p = \frac{100}{s-10}$$

is controlled by a proportional controller with gain $k_c$.

(10%) (a) Using the Nyquist theorem test the closed loop stability for $k_c = 1$ and $k_c = 0.1$.

(10%) (b) Using the Nyquist criterion, compute the limiting value of $k_c$ for which the system is stable.

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**Problem #5:** (20% total)

A first order process is given by

$$G_p(s) = \frac{1}{s+5}$$

This process is controlled by a proportional-derivative (PD) controller given by:

$$G_c(s) = k_c(1 + \frac{1}{s})$$

(10%) (a) Compute values of the $k_c$ that will result in closed loop stability. Use the Routh stability test. Assume for valve and sensor transfer functions $G_V = G_m = 1$

(10%) (b)For a controller gain $k_c=1$ compute the closed loop time response for a unit step change in setpoint .

**Problem #6:** (20% total)

A process given by

$$G_p(s) = \frac{e^{-\frac{3\pi}{4}s}}{s+1}$$

is controlled by a proportional controller with proportional gain $K_c$.

(10%) (a) Without using any approximations, test stability for $K_c=1$. What is the critical frequency?

(10%) (b) What is the gain margin for $K_c=1$?

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**Problem #7** (20% total)

For the process modelled by:

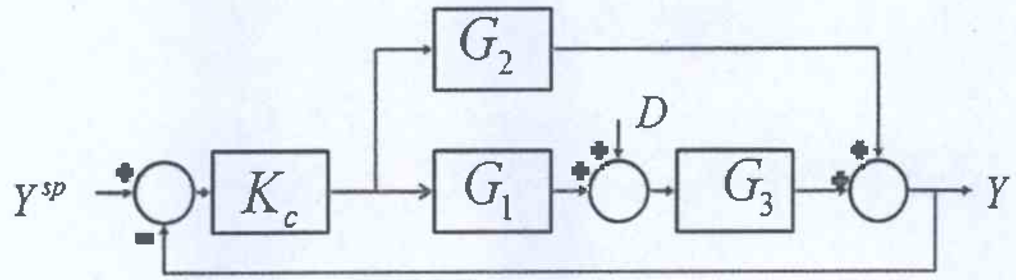
$$\frac{dy_1}{dt} = -y_1 - y_2 + x_1$$

$$\frac{dy_2}{dt} = y_1 - 2y_2 + x_1 + x_2$$

(10%) (a) Find the two transfer functions relating the inputs $x_1$ and $x_2$ to the output $y_2$. The x's and y's are deviation variables.

(10%) (b) Compute $y_2$ as a function of time for $x_1 = 0$ and a unit step in $x_2$.

**Problem #8** (20% total)




For the block diagram in the figure:

$$G_1 = 10 \quad G_2 = \frac{2}{3s+1} \quad G_3 = \frac{1}{s-1}$$

is controlled by a proportional controller with gain $k_c$.

(10%) (a) Find the closed loop transfer function Y(s)/D(s). What is the characteristic equation of the system (to be used for testing stability)?

(10%) (b) Find the values of $K_c$ for which the closed loop is stable.